Neuromechanical adaptations in joint stiffness when hopping with a SL-AFO

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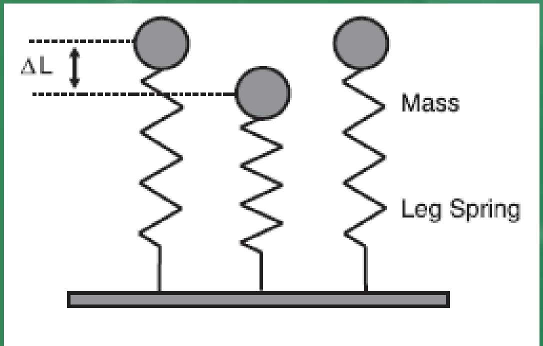
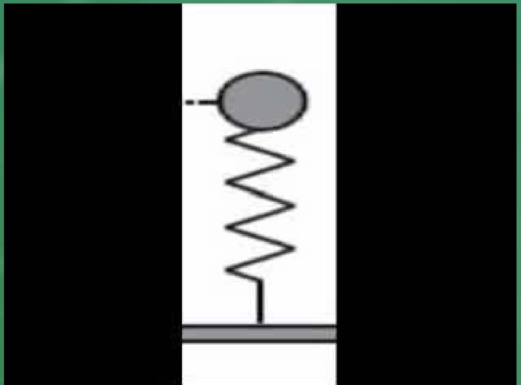
Introduction

- The human body is modeled to behave like a spring-mass system during bouncing gaits such as running and hopping.[1-4,21, 23]

- The **leg's stiffness** influences:[2,3,5-7]
  - peak ground reaction force
  - ground contact time
  - center of mass displacement
  - stride frequency
  - "stiffness is the primary control variable in motor behavior." [9]

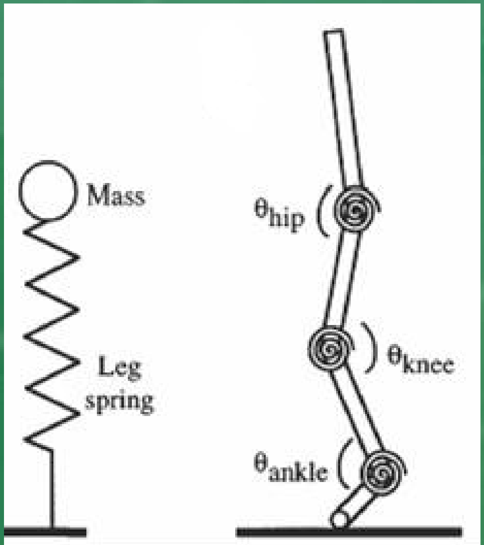


Ferris et al, 2006



Significance

- Basic Science Question:
  - Understand how local control variables are adjusted to maintain stable global tasks.[11, 19-20]
    - during hopping leg stiffness (global task) is modulated at the ankle (local variable) with different pertubations:[5-6,8]



[Farley et al, 1998]

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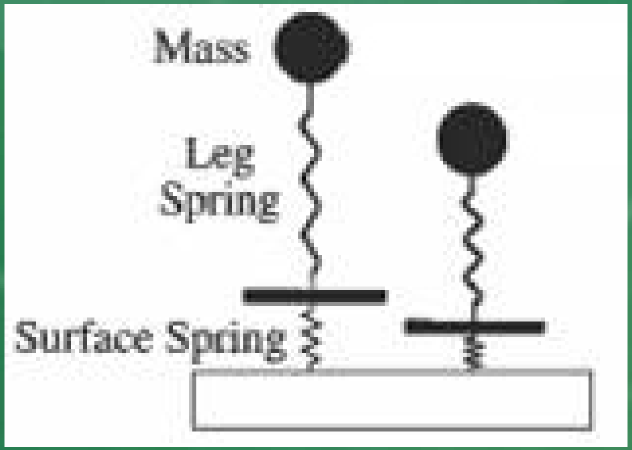
      - an elastic element in series



[Ferris et al, 1997]

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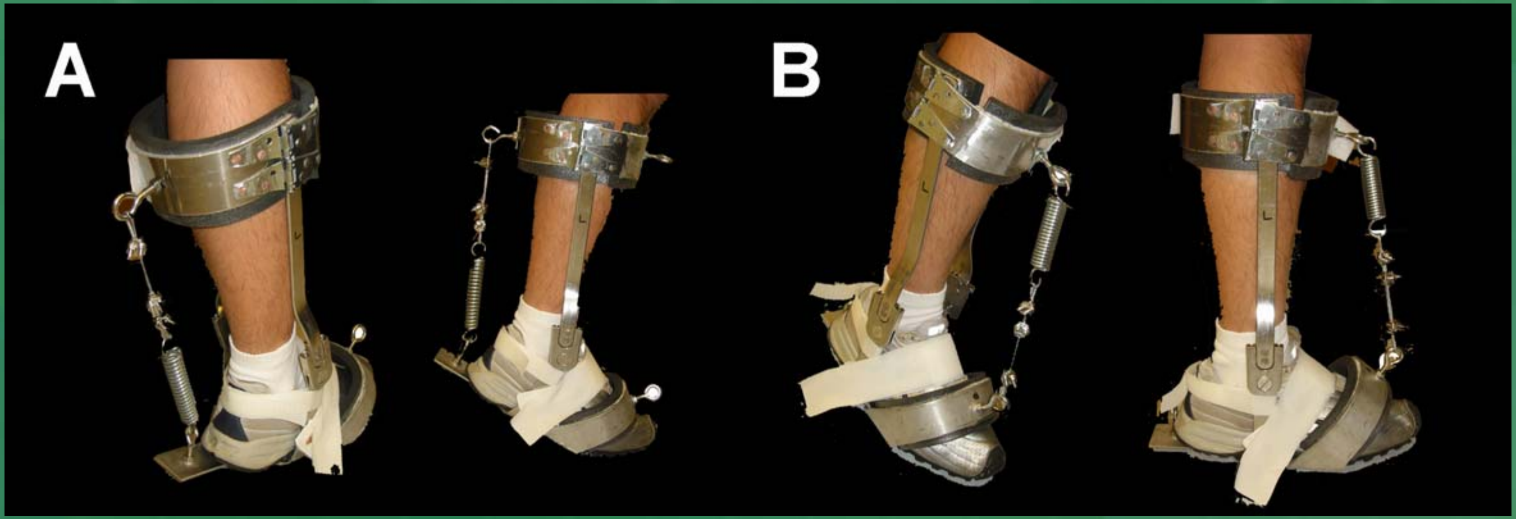
    - during hopping leg stiffness (global task) is modulated at the ankle (local variable) with different pertubations:[5-6,8]
      - an elastic element in parallel [5]

[Ferris et al, 2006]

Hypothesis

Hypothesis A: When a spring is added in parallel to the leg to create a *plantar-flexor* torque, the effective leg stiffness will stay the same, but the biological ankle stiffness will *decrease*.

Hypothesis B: When a spring is added in parallel to the leg to create a *dorsi-flexor* torque, the effective leg stiffness will stay the same, but the biological ankle stiffness will *increase*



Research Design & Methods

- Subjects‡ :
  - Inclusion Criteria: no major muscular or skeletal injuries, or neurologic conditions
  - 10 Total: 6 Male, 4 Female
  - Avg. Weight: 61.34 Kg (11.16)　　Avg. Age: 25.4 y/o (2.46)

- Protocol:
  - 3 conditions*‡: AFO, AFO w/ PFA, AFO w/PFR
  - 3 frequencies for each condition**‡: 2.2 Hz, 2.4 Hz, and 2.8 Hz
  - 3 trials for each condition-frequency combination
  - 10 sec of hopping on Right Leg for each trial when frequency is reached
  - ~30 hops were analyzed per condition

* 3 trials taken at preferred frequency with no AFO
** 3 trials taken at 2.2Hz with no AFO
‡INDEPENDENT VARIABLES

- Instrumentation used: Vicon Motion Capture system, AMTI Force Plate, Konigsberg 8-channel bi-polar EMG, and an Omega Force Transducer

- Statistical Methods
  - Three-Way AVOVA: Repeated Measures
  - Post-Hoc: Bonferroni

General Procedures:

Data Analysis

Dependent Variables:

Leg stiffness = Linear Regression **(Δ vGRF / Δ COM)**

- Units: N / m
- vGRF (from Force plate)
- COM = $\iint$ vGRF/m dt^2

Total Joint stiffness = Linear Regression **(Δ M / $\Delta\theta$)**

- Units: Nm / rad
- M (inverse kinematics)
- $\Delta\theta$ (from Vicon)

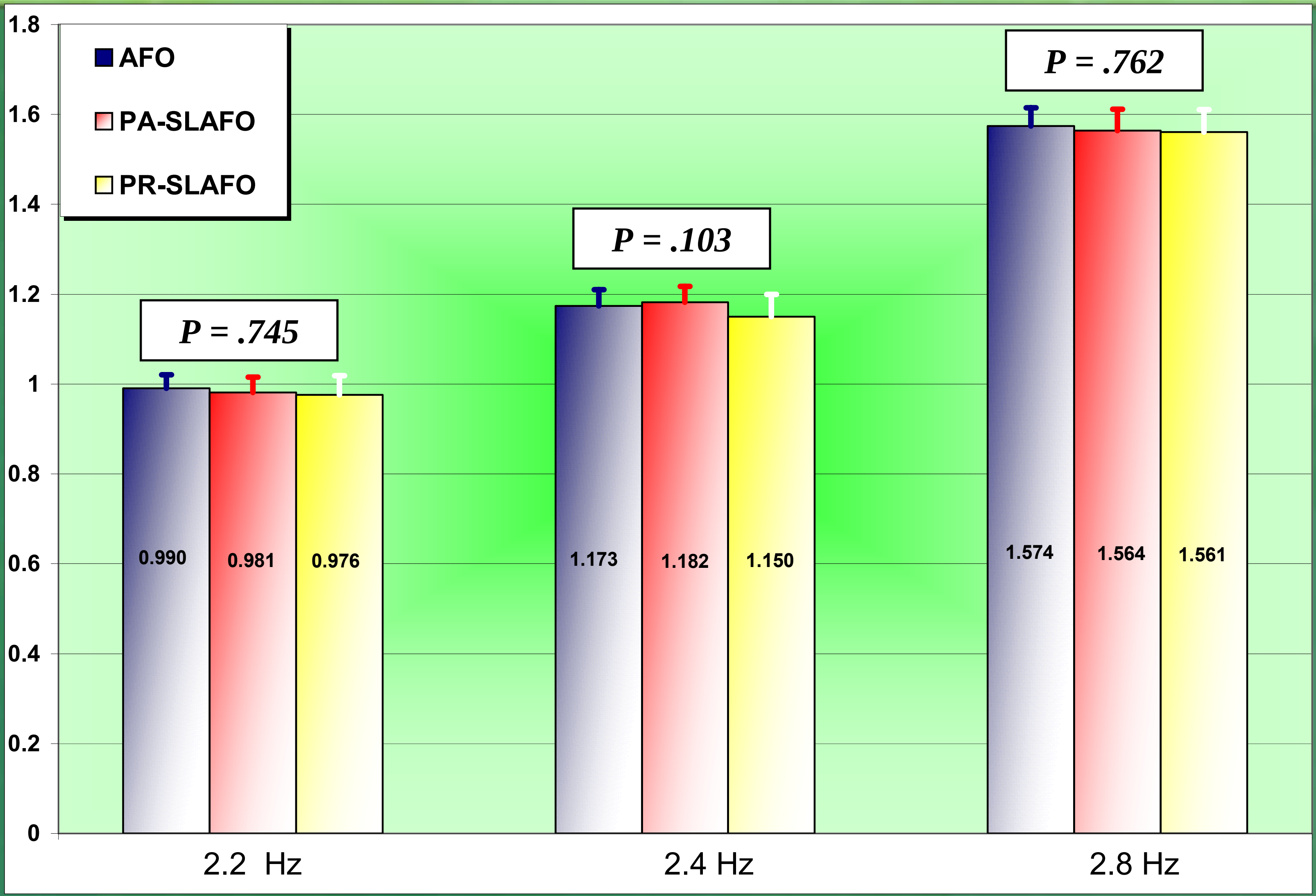
Orthosis Ankle Stiffness = Linear Regression **(Δ F_{FT} x d_{sp} / Δ θ)**

- Units: Nm / rad
- F_{FT} (force transducer)
- d_{sp} (geometric model of spring moment arm)

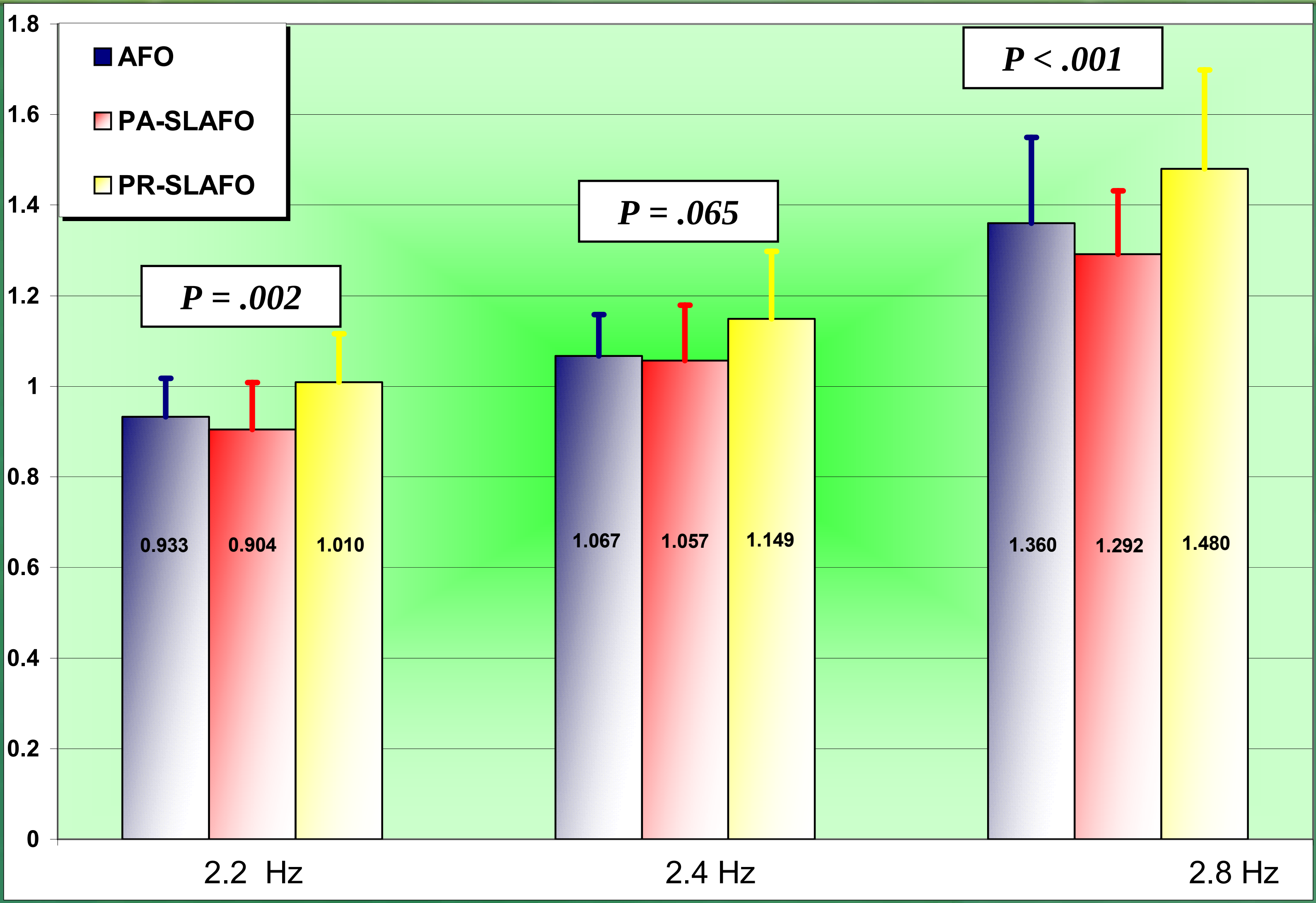
Biological Ankle Stiffness = **Total Ankle Stiffness – Orthosis Ankle Stiffness**

- Units: Nm / rad

Normalized Leg Stiffness (N = 10)



Normalized Total Ankle Stiffness (N=10)



Study Limitations

- AFO may not be universally designed for all subjects
- Spring length predetermined for all subjects, rather than for each person
- Spring stiffness predetermined for all subjects rather than for each person
- Inclusion criteria for data was: Hopping $\boldsymbol{f}$ **± 3%**; $\boldsymbol{f \propto k^2}$ which implies **k** may vary **± 9%**

Discussion

- Leg stiffness was maintained within a frequency, though it is not mechanically necessary to do so.[3,7]
  - Therefore it is shown that the global task (leg stiffness) is maintained under new perturbation paradigm; i.e., with a dorsi-flexor torque.
  - To maintain an invariant effective leg stiffness with this perturbation requires that compensation is occurring at one or more of the joints – though which one it is has yet to be deciphered since it does not appear to be entirely at the ankle.

Application

- Further insight into a rehabilitative modality achieved
  - With variable assistance/resistance we can work toward therapeutic AFOs
- More sophisticated rehabilitation devices could be made effectively. [14-18]
  - Compliance of device (e.g. a PLS-AFO or GRF-AFO) could directly impact the effective stiffness of the joint it is being applied to.

Mehrholz et al, 2005

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  - Heather Brant

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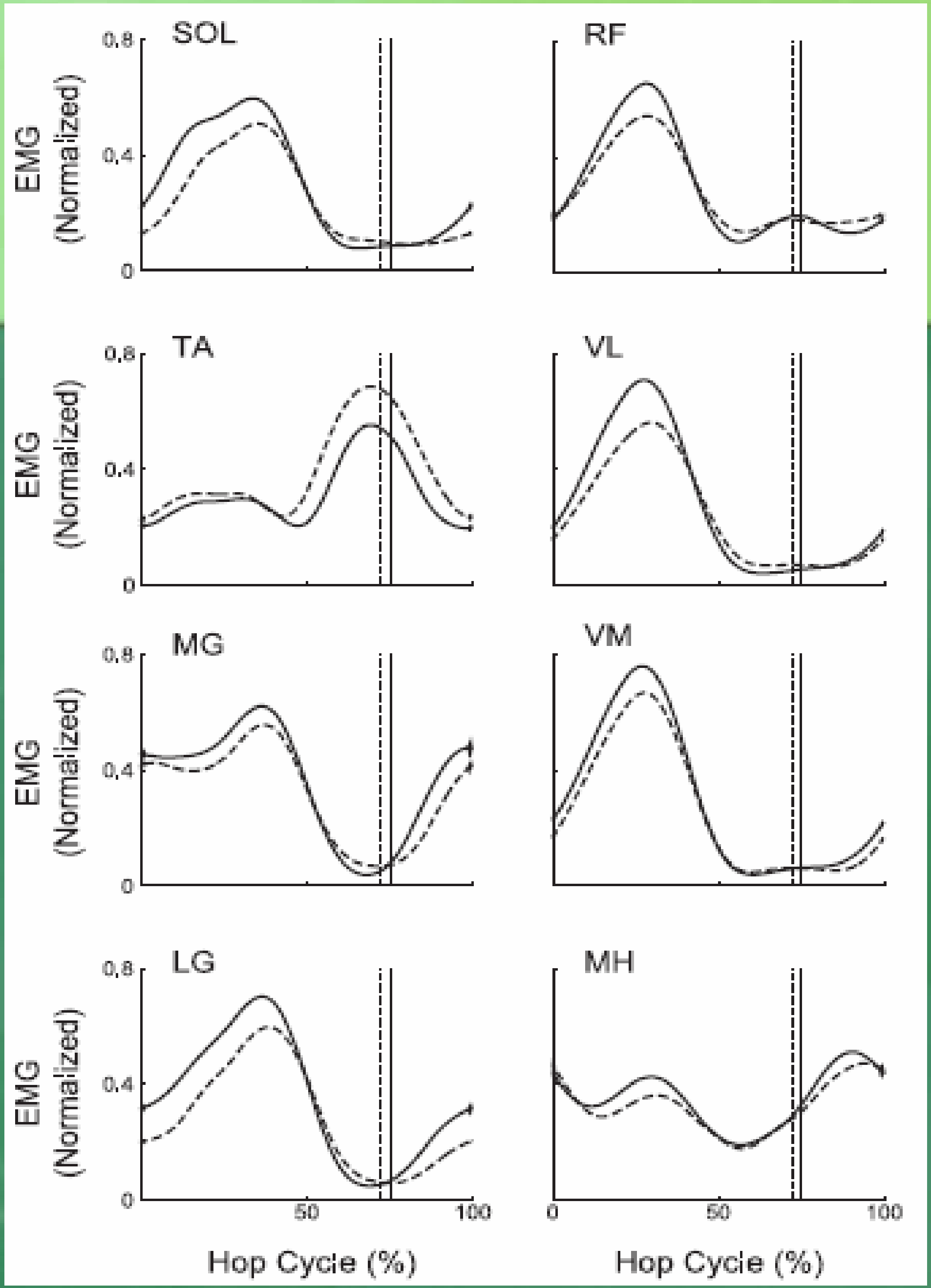
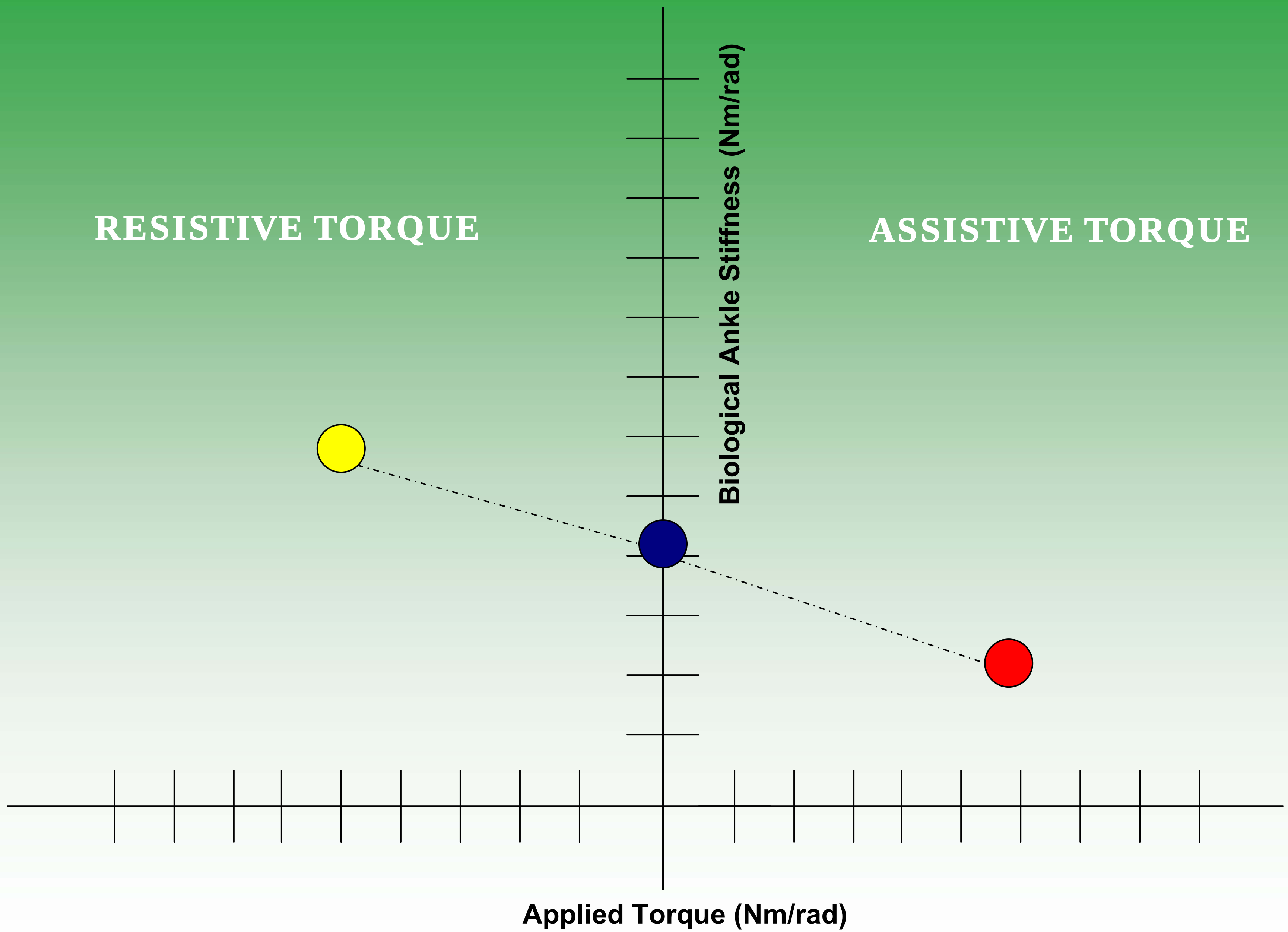
Use of EMG

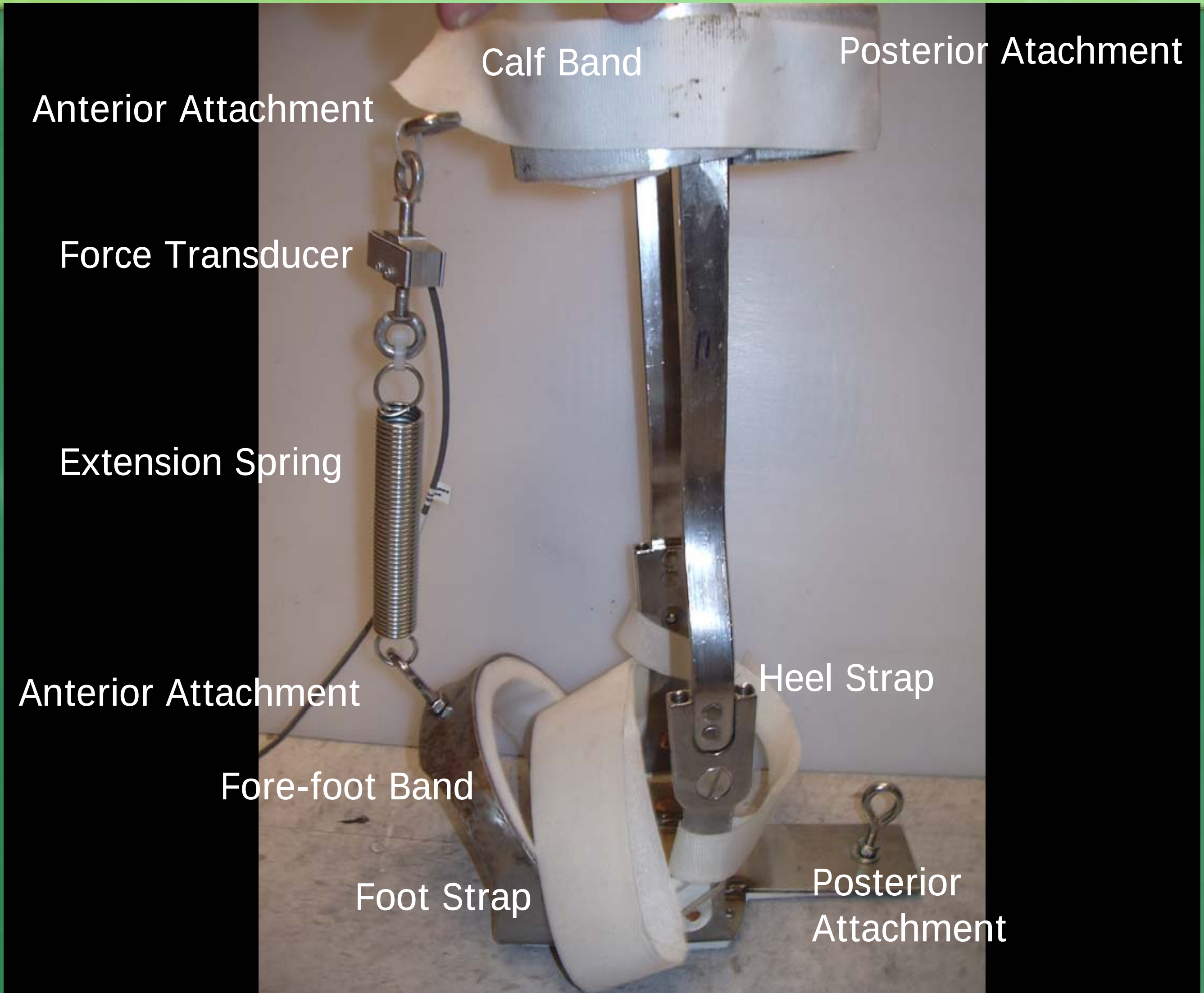
- Physiological Check:
  - "joint stiffness" varies with muscle activation[5]
  - variations to be expected with the main flexors/extensors surrounding the ankle and knee



Ferris et al, 2006


RESISTIVE TORQUE
ASSISTIVE TORQUE
Biological Ankle Stiffness (Nm/rad)
Applied Torque (Nm/rad)

SL-AFO


Calf Band
Posterior Atachment
Anterior Attachment
Force Transducer
Extension Spring
Anterior Attachment
Heel Strap
Fore-foot Band
Foot Strap
Posterior
Attachment